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THE PROPAGATION OF CITRUS BY CUTTINGS[1]

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The commercial method of propagating citrus in the United States consists of budding the desired variety onto a seedling rootstock. The principal commercial scion varieties in California are Eureka and Lisbon lemon (*Citrus limonia* Osbeck),[3] Valencia and Washington Navel orange (*Citrus sinensis* Osbeck), and Marsh grapefruit (*Citrus grandis* Osbeck). The standard rootstocks are seedlings of sweet orange (*Citrus sinensis* Osbeck), sour orange (*Citrus aurantium* Linn.), grapefruit (*Citrus grandis* Osbeck) and to a limited extent rough lemon (*Citrus limonia* Osbeck). Since a budded citrus tree is a combination of either two species or two varieties of the same species, a study of the effect of the rootstock variety, or the effect of the presence of a bud union, must necessarily include a comparison of budded trees with unbudded trees, that is, with trees propagated by cuttings.

The writer's investigation of cutting propagation has been undertaken primarily because of its bearing on the problem relating to stocks for citrus budding. However, this method may be useful also in commercial propagation of citrus, or in the production of plants for experimental physiological and pathological study.

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[3] The taxonomic nomenclature is that of Swingle.(11)

It has long been known that the citron and the lemon may be propagated readily by cuttings, but writers on the subject apparently doubt the possibility of propagating the sweet orange and the grapefruit by this method. Swingle and his associates[12] have used a method similar to that employed by the writer but found that the sweet orange was difficult to propagate from ordinary cuttings, no matter how carefully they are handled. Coit[1] is of the opinion that orange cuttings are so difficult to grow that this method of propagation is altogether impracticable. Hume[10] expresses a similar view, stating that cuttings of the grapefruit and orange are more difficult to root than the lemon, and though it may be accomplished, this method for these trees has little to recommend it and is not commercially practicable.

Preliminary experiments at the University of California Citrus Experiment Station conducted by the writer in 1926[5] showed that, although the sweet orange and grapefruit root less readily than the lemon, yet a commercially satisfactory percentage of rooted plants can be obtained if the cuttings are taken from healthy vigorous trees, and the leaves on the cuttings are left intact.

In view of the fact that this investigation has been discontinued it was thought advisable to publish the results obtained from 1926 to 1930. This paper deals with the propagation of twig and root cuttings and with grafted twigs handled like cuttings.

EXPERIMENTAL METHODS AND RESULTS WITH CUTTINGS

Cuttings 10 to 15 cm long, possessing five to six nodes, are made from the mature terminal growth. With oranges and grapefruit, experience has shown that it is important to take the material from healthy, vigorous trees and that the leaves of the cuttings be healthy, mature, and free from injury. The lower two or three leaves are removed, thus leaving three or four leaves on the cuttings (fig. 1). Retention of the leaves is essential for satisfactory results; reducing the leaf area by cutting off the terminal half of the leaves has been found to retard and to reduce the amount of roots produced by the cutting.[4] Table 1 shows that while lemon leaves without stem (fig. 2) rooted satisfactorily, the seven-node stem cuttings without leaves failed to produce a measurable amount of roots. If an abundance of material is available, longer cuttings with correspondingly greater number of leaves may therefore be used with advantage.

[4] The relation of leaf area to root production will be discussed later.

TABLE 1

RELATION OF QUANTITY OF LEAVES TO QUANTITY OF ROOTS PRODUCED; EUREKA LEMON CUTTINGS GROWN FOR 55 DAYS (NOV. 29, 1929 TO JAN. 23, 1930)

Type of cutting	Number of leaves	Number of rooted cuttings	Fresh weight, per cutting: Leaves	Fresh weight, per cutting: Roots	Weight of roots per 100 grams of leaves
			grams	*grams*	*grams*
Leaf	1	29	1.56	0.24	15.38
Stem*	0†	4	....	....	....
	1	45	1.37	0.35	25.55
	2	41	2.33	0.52	22.32
	3	46	3.96	0.74	18.69
	4	46	4.78	1.02	21.34
	5	36	5.00	0.95	19.00
	6	9	7.39	1.31	17.73
	7	13	7.91	1.34	16.94

* All stem cuttings possessed seven nodes with the exception of cuttings with six and seven leaves which had nine nodes.

† Only 4 out of 27 cuttings rooted and the amount of roots produced was insignificant. The other lots rooted close to 100 per cent.

Whether the basal cut is made immediately below a bud or above is not important, but there seems to be a relation between the degree of slope of the basal cut and the number of roots which develop; the greater the slope the fewer the number of roots produced. This is shown in table 2. When a 90° cut was made and then four narrow equally-spaced grooves were made at the cut end, thus limiting root activity to four definite places, a considerable increase in number of roots occurred, although the amount of roots per unit weight of leaf was not increased.

TABLE 2

EUREKA LEMON CUTTINGS SHOWING THE EFFECT OF TYPE OF BASAL CUT ON THE NUMBER OF ROOTS PRODUCED; FORTY-FIVE CUTTINGS IN EACH LOT*

Type of cut	Number of roots: Mean	Number of roots: Standard deviation	Green weight of roots per 100 grams of green leaves	Dry weight of roots per 100 grams green leaves
			grams	*grams*
Slope of 40–50 degrees	$3.3\pm.14$	$1.4\pm.10$	16.3	1.9
Slope of 60–70 degrees	$3.1\pm.14$	$1.4\pm.10$	17.2	2.0
No slope	$3.8\pm.17$	$1.7\pm.12$	16.4	1.9
No slope, 4 grooves	$4.5\pm.11$	$1.1\pm.08$	16.0	1.8

* The total green weight of stems for each lot varied from 64 to 67 grams.

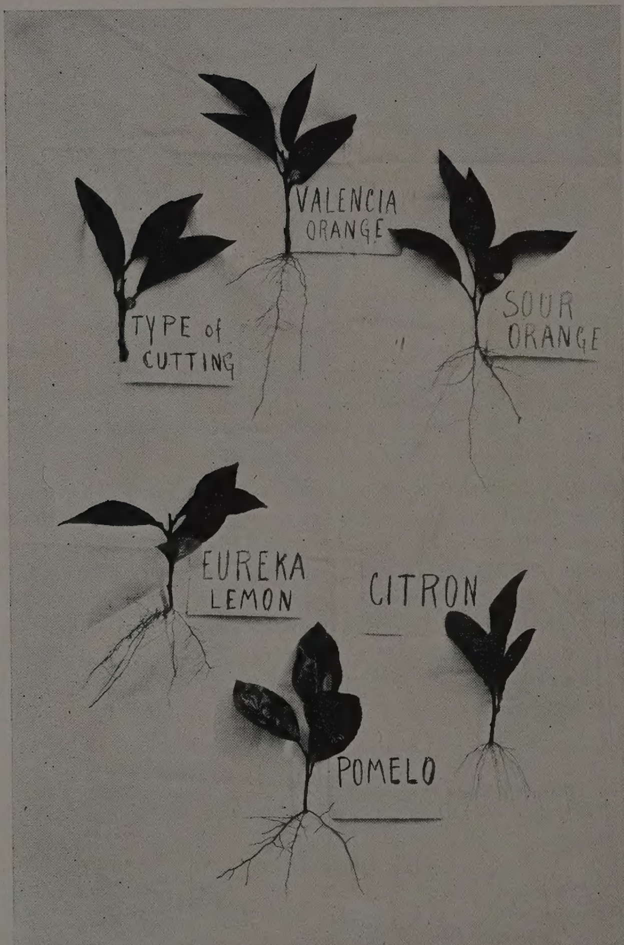

Fig. 1. Type of cutting used in propagation and several varieties of rooted cuttings 6 weeks old.

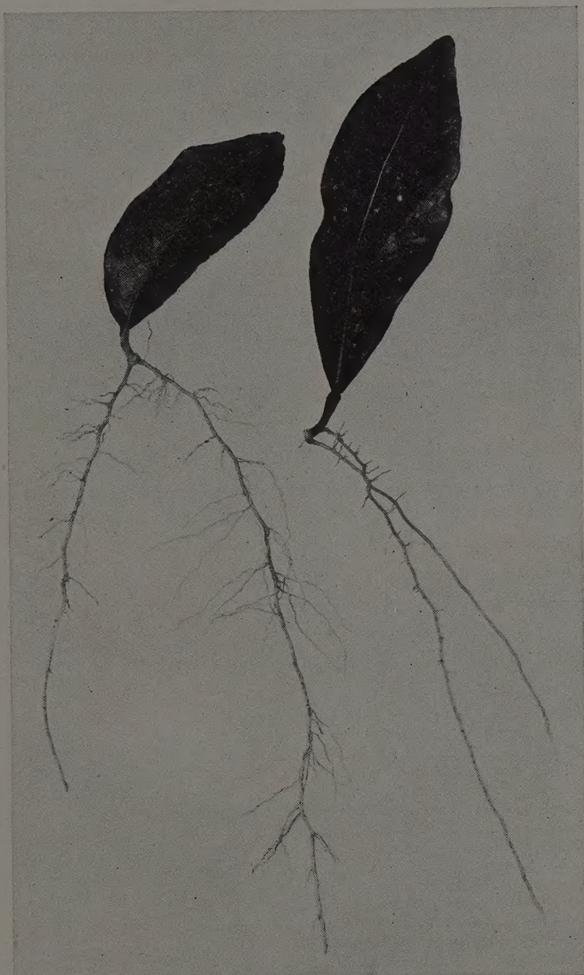

Fig. 2. Rooted Eureka lemon and Valencia orange leaf cuttings.

The cuttings are placed in sand in a sash-covered propagating frame and shaded with material such as burlap to prevent leaf burn. Until roots have developed, the leaves must be kept turgid by the maintenance of high humidity. This requires strict limitation of ventilation and frequent sprinkling with water. During cool weather, bottom heat is necessary to insure rooting of orange and grapefruit cuttings and is beneficial in the case of the lemon. Satisfactory results have been obtained by maintaining the temperature of the sand at 24° to 26° C (75° to 79° F). Cuttings can be successfully rooted in hot weather, however, when the temperature of the sand often rises to 43° C and the air is doubtless still warmer.

Some of the varieties of *Citrus* and species of genera closely related to *Citrus* which have been grown successfully from cuttings are listed in table 3. Where a sufficient number of trials were made, the average percentage of rooted cuttings obtained is noted.

TABLE 3

A LIST OF VARIETIES OF CITRUS AND SPECIES OF GENERA CLOSELY RELATED TO CITRUS WHICH HAVE BEEN GROWN FROM CUTTINGS

Variety	Average per cent of rooted cuttings
Citrus limonia, Osbeck (lemon)	98
Citrus medica, Linn (citron)	100
Citrus aurantium Linn (sour orange)	92
Citrus sinensis, Osbeck (sweet orange)	85
Citrus grandis, Osbeck (grapefruit)	75
Citrus nobilis, Lour. var. deliciosa, Swingle (Mandarin orange)	75
Citrus nobilis, Lour. var. unshiu (Satsuma or Unshiu orange)	....
Citrus webberii	....
Citrus mitis, Blanco (Calamondin orange)	....
Citrus hystrix	....
Citranges (Hybrids between Citrus sinensis and Poncirus trifoliata)	....
Aegle marmelos, Correa	....
Atalantia citrioides, Pierre	....
Balsamocitrus dawei, Stapf	....
Balsamocitrus gabonensis, Swingle	....
Chalcas exotica, Millsp. (Orange Jessamine)	....
Citropsis schweinfurthii, Swingle and M. Kellerman	....
Citropsis gabonensis, Swingle and M. Kellerman	....
Clausena lansium, Skeels	....
Fortunella margarita, Swingle (kumquat)	....
Lavanga alota	....
Microcitrus virgata	....
Poncirus trifoliata, Raf	....
Severinia buxifolia, Ten	....

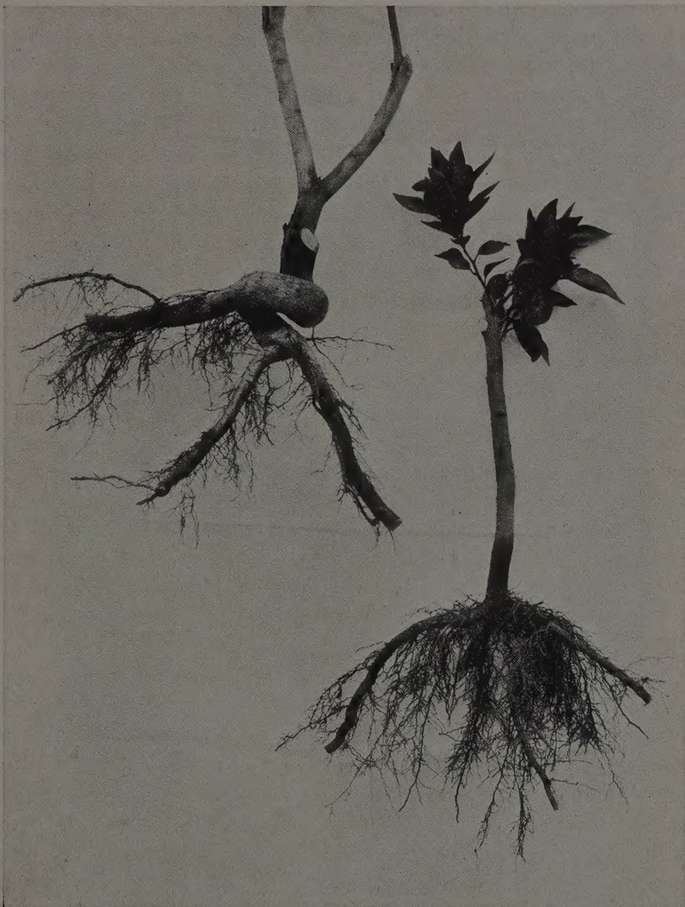

Fig. 3. Navel orange cuttings. Upper one three years old showing curled roots due to pot-bound condition at time of planting in nursery. Lower one two years old was transferred directly from the propagating frame to the nursery.

The percentage of cuttings which root may vary considerably in the same variety if the material is taken from weak trees. For example, cuttings taken from fifteen Valencia orange trees of the same age and growing in the same orchard rooted 60 per cent to 97 per cent, the weaker trees giving the lower percentages. Again Navel orange cuttings taken from eleven trees in the same orchard in 1926 averaged 87 per cent, while two years later material taken from the same trees which were then declining in vigor averaged 57 per cent.

Generally, after two or three months the cuttings will have developed fairly extensive root systems (fig. 1). Before transplanting to the nursery the plants must be hardened by gradually lowering the atmospheric humidity, which is done by admitting outside air into the frame. The plants are then lifted from the sand and planted bare-rooted in the nursery row. New growth is removed but the original leaves are left, as experience has shown that they are essential to the establishment of the transplanted cutting. Potting the plants from the cutting bed not only entails additional expense and labor but also results in curled roots, a condition which becomes worse as the trees get older (fig. 3). If the plants have well-developed root systems they can be transferred directly to the nursery even though the weather be hot and dry, provided they are watered immediately and protected from direct sunshine by shading. This is usually accomplished by the use of one or two shingles. Since young cuttings have a shallow root system, deep cultivation in the root zone must be avoided. Figure 4 shows one-year-old Valencia orange cuttings in the nursery.

The plants are left in the nursery until they are large enough for planting in the orchard. Lemon cuttings generally reach the size of saleable budded trees in two years and the sweet orange and grapefruit in two or three years (figs. 5, 6, 7).

The method just described appears to be the most practicable for the conditions and needs of the citrus industry in California. There are doubtless other, and perhaps equally successful, means of propagating citrus trees by cuttings. The lemons and citron, for example, can be successfully propagated by planting directly in the nursery larger cuttings devoid of leaves, though in this case the plants require more time to develop. For the sweet orange and grapefruit this procedure has not been found successful.

Fig. 4. Valencia orange cuttings in nursery, one year old and trained to one stem. Note the variation in height although they are progenies of one tree.

Fig. 5. Navel orange cutting in nursery, three years old, not trained to single stem. The upright growth (nearly 2 meters high) developed during the third year.

Fig. 6. Lisbon lemon cutting in nursery three and a half years old, which made a well-shaped tree without training; about 2½ meters high.

Fig. 7. Marsh grapefruit cutting in nursery three years old which made a low but shapely tree without training; over 1½ meters high.

CUTTINGS VERSUS BUDDED TREES

There are no indications in the nursery that trees grown from cuttings are inferior to budded trees, but a comparison as to their fruitfulness and longevity cannot be made until the trees reach maturity, and this comparison should be made where both kinds of trees represent the same scion strain. Assuming, however, that cuttings may be as satisfactory as budded trees it may be of interest to point out the advantages and disadvantages in the two methods as the writer sees them at this time.

Advantages of Cuttings.—1. Cuttings can be made at any time of the year, while budding is confined to the growing season.

2. Less time is required to grow a tree of suitable size for planting in the orchard. The principal reason for this lies in the fact that cuttings grow uninterruptedly in the nursery until they are set out in the orchard, whereas the growth of the root system of the budded seedling is checked when the top is cut off to force the bud into growth.

3. If a tree on its own root is killed back to the ground, a sprout from any living part will be of the same variety as the original top, but with budded trees a sprout from below the bud union will have to be budded again.

Disadvantages of Cuttings.—1. For cuttings more material has to be cut from the parent tree than for budding seedling stocks.

2. Since the lemon is very susceptible to *Pythiacystis* gummosis, cuttings of this species may be short lived in sections where this disease is important.

Doubtful Features.—1. The root system of cuttings is shallow, at least for the first two or three years. It has been observed, however, that the root system of many old budded trees on sweet orange or grapefruit rootstock is also shallow; in many cases it does not penetrate beyond 1 meter (40 inches). Nevertheless budded nursery plants have a deeper root system than cuttings, which lessens the danger that they will be blown over by wind after they have been set out in the orchard, and also facilitates balling for transplanting.

2. It is difficult at the present stage of the investigation to compare the cost of growing cuttings and budded plants because the cuttings were not grown on a commercial scale. The cost of lemon

cuttings is undoubtedly less than that of budded plants since they can be rooted in an ordinary cold frame. Orange and grapefruit cuttings, however, require bottom heat during the greater part of the year and more skillful handling than the lemon. The expense is further increased over that of lemon cuttings because the percentage of rooted orange and grapefruit is smaller.

3. It is doubtful whether greater uniformity in size of plants can be obtained with cuttings than with trees produced by budding on seedling stocks. Measurements of height of one-year-old Valencia orange and Navel cuttings and three-year-old sweet orange seedlings growing in the same nursery showed no significant difference in variability between cuttings and seedlings (table 4). Due consideration must be given however, in this case, to the difference in age of seedlings and cuttings. It is highly probable that most of the seedlings resulting from selfing of sweet orange are, as a rule, the result of apogamic (asexual) reproduction (Frost[2]). It is therefore to be expected that most of the seedlings will be identical in genetic constitution with the seed parent, and that most of the differences among them will be due to the same 'accidental' causes as with cuttings.

TABLE 4

Height in Centimeters of Sweet Orange Seedlings 3 Years Old and of Valencia and Navel Orange Cuttings 1 Year Old

Orange	Number of plants	Mean	Standard deviation	Coefficient of variation
Navel orange cuttings	94	38.3±0.6	8.4±0.4	21.9±1.1
Valencia orange cuttings	195	42.7±0.6	11.8±0.4	27.6±1.0
Sweet orange seedlings	90	121.7±1.9	26.4±1.3	21.7±1.1
Sweet orange seedlings	106	138.0±2.1	31.9±1.5	23.1±1.1
Sweet orange seedlings	91	147.8±2.3	31.7±1.6	21.4±1.1

Aside from environmental influences, the amount of variation with cuttings depends to some extent (as is shown below) on the total original leaf area of the cutting, just as the variability of the apogamic seedlings is doubtless affected by differences in size of embryo. Also any pruning given to seedlings or cuttings will obviously influence the variability in size of plant. For example, if some of the original leaves are removed from a rooted cutting the subsequent growth of the plant will be less than that of a plant whose leaves are left intact.

OTHER APPLICATIONS OF THE METHOD — TWIG GRAFTS

In rootstock investigations it is necessary to have plants representing combinations of scion and stocks of known varieties. This can be accomplished by growing cuttings of the variety which is to serve as the rootstock, and then budding them to the desired scion variety. This method requires the same length of time as the ordinary budding method.

Fig. 8. Twigs grafted together, before and after rooting.

A rapid and satisfactory method developed by the writer[5] consists of tongue-grafting together two leafy twigs representing the desired stock and scion varieties, tying the graft union with raffia,

and then treating the twig graft like a cutting (fig. 8). The graft generally unites within two weeks. Rooting depends, as with an ordinary cutting, upon the variety. Limited data suggest that the rate at which a twig graft roots is governed by the variety serving as the rootstock if the stock is provided with healthy mature leaves. For example, if the rootstock is a Eureka lemon and the scion a Valencia orange, rooting proceeds at a faster rate than in the reverse combination. However, as the plants become established in the nursery the rate of growth seems to be governed by the scion variety.

Plants propagated by this method compare favorably with budded plants, but the important advantage lies in the fact that strong plants representing various combinations can be developed within one year and plants suitable for water cultures within a few months. This method may also offer a means by which congeniality between untried citrus varieties can be tested.

THE PROPAGATION OF THE ROOTSTOCK OF MATURE TREES

Mature citrus trees of the same age often exhibit a great variation in size and yield. In orchards where soil and other conditions for growth are fairly uniform and the rootstocks are all of the same species, variation is often due to differences in scion strain. In some cases this is quite apparent, but in other cases it is necessary to grow the progenies of the scions to obtain the proof (Halma[9]). It is obvious, however, that stocks, all of one species, may be of different types (varieties or strains). Since citrus stocks are grown from seed and this seed is obtained from various sources, it is probable that stocks of one species such as sweet orange, for example, may include types differing as widely as any of the horticultural varieties like the St. Michael and the Valencia. There may also be less marked differences such as occasionally originate by bud variation within a budded variety and are commonly called strains. Such types may differ in various ways, as in general vigor, in soil and climatic adaptation, and in congeniality with particular scion varieties and even particular types of those varieties. A thorough investigation of tree variability therefore should include a study of the rootstock type. For example, if rootstock progenies were available it would be a simple matter to effect a recombination of the scion and stock strain of a given tree and thus find whether in the case of a superior tree the scion and

stock strains are especially congenial, or whether in a poor tree there is lack of congeniality. Obviously any rootstock study of mature budded trees entails vegetative propagation.

In general there are three methods by which the rootstock of mature trees may be propagated without injury to the top: (1) By forcing sprouts from below the bud union and using these sprouts for bud wood or cuttings. In the writer's experience this method has failed in every instance, whether the trunk was notched or deep cuts into the wood made with a saw. (2) By severing a root and lifting the cut end of the severed root above the soil surface. It appears that the roots of young trees respond fairly readily to this treatment, but old trees do not, with exception of rough lemon, which is of minor importance in California, at least as far as old trees are concerned. (3) Propagation by root cuttings was tried by placing root pieces in the propagation frame and in soil under shade and in the nursery. A few cuttings produced weak sprouts which died before they became mature; none rooted. Attempts to stimulate root formation by injecting into the root pieces solutions of potassium permanganate, glucose, cane sugar, thiourea, sodium nitrate, and calcium nitrate failed.

Finally a method was devised (Halma[6]) which is simple and gives satisfactory results. It consists of grafting onto a root piece, about 10–15 cm long and about 1 cm in diameter, a healthy leafy citrus twig of the type used for a cutting (fig. 9). Limited observations indicate that the lemon is a more satisfactory scion variety than either the orange or grapefruit. Satisfactory material for studying congeniality may be obtained by making the desired combinations, as for example, root pieces and scion from the same tree, root pieces from a good tree and scions from a poor tree, etc.

Either the tongue or bark-graft method may be used but, if the root-piece is of sufficient size and the bark slips, bark grafting is preferable. The union is tied with raffia and the grafted root piece is placed in the propagation bench and treated like a cutting. There is no advantage in sealing the graft union with grafting wax or paraffin. Generally within one or two weeks the scion will have united with the root piece, and if the latter does not decay rootlets appear sometimes in two weeks (fig. 9). The beneficial influence of a leafy scion upon root development can be demonstrated also with grafted and ungrafted lemon roots (fig. 10).

Fig. 9. Grafted root pieces before and after rooting.

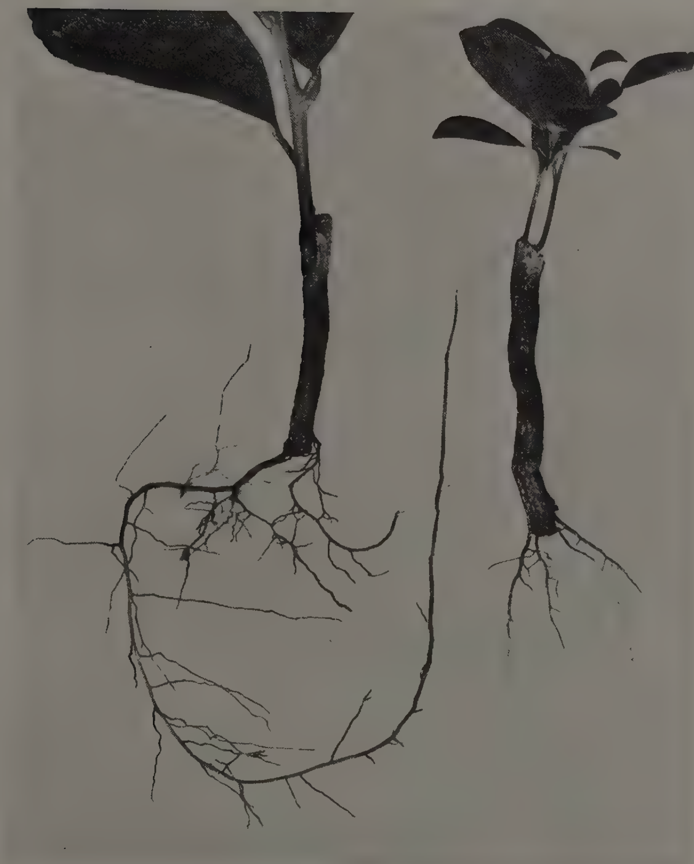

Fig. 10. Lemon root cuttings showing the quantitative difference in root development between grafted and ungrafted pieces.

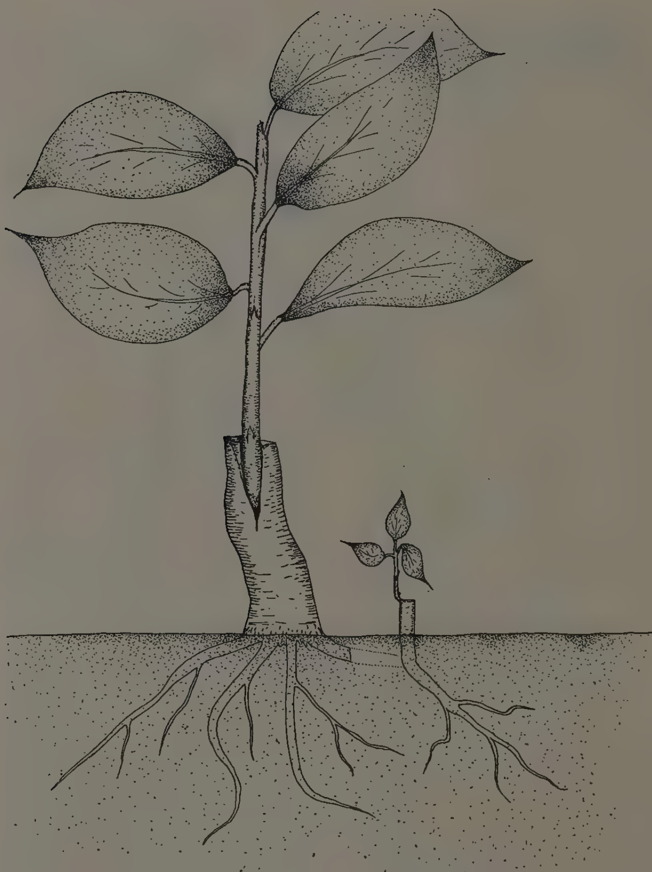

Fig. 11. Method of obtaining root sprouts from grafted root pieces.

After about three months the rooted plants are transferred to the nursery. If the plants represent combinations suitable for studying congeniality they may be set out in a permanent place in about two years. But if the plants were grown for the purpose of observing differences in rootstock strains it is, of course, necessary to induce sprout growth from the root piece by cutting off the scion. It has been found, however, that the plant must be at least two years old before this is done, or the root piece dies. Instead of cutting off the scion the safer procedure is to sever one of the young roots and raise its cut end above the ground (fig. 11); if sprouts fail to develop the mother plant is still available for further use. Limited data suggest that the best time to force sprouts from a young root or the root piece itself is during March or April.

The percentage of rooted plants obtained with grafted root pieces varies considerably more than that of twig cuttings. One lot of grafted root pieces may yield 70 per cent and another lot from the same tree only 10 per cent. This cannot be due to the scion because it remains in good condition long after the root piece has decayed. Cross sections of many apparently sound root pieces which failed to produce roots showed that the majority of the tracheae were plugged with a gummy substance, while roots which grew were free from it (figs. 12 and 13). In severe cases the gummy deposits can be seen with the unaided eye. Observations indicate that roots containing gummy deposits are most prevalent in the upper layer (about 30 cm) of soil. Furthermore, roots which have been repeatedly mutilated as a result of cultivation always show this abnormal condition even though the injury may be some distance away.

THE LEAF IN RELATION TO ROOTING

The importance of the leaf in the propagation of citrus by cuttings has already been emphasized, but it may be profitable to give experimental evidence which has a bearing on this subject. By growing leaf cuttings (fig. 2) it was found that both the area and green weight of the leaf are positively correlated with the amount of roots produced. This is also true of leafy twigs, which indicates that the stem itself plays a minor part in the rooting of the type of cuttings used (table 5). Experiments carried on with large citron cuttings without leaves and undetached lemon shoots in the orchard also showed that the amount of twig growth produced is positively correlated with the size of the cutting or undetached shoot (Halma[7]).

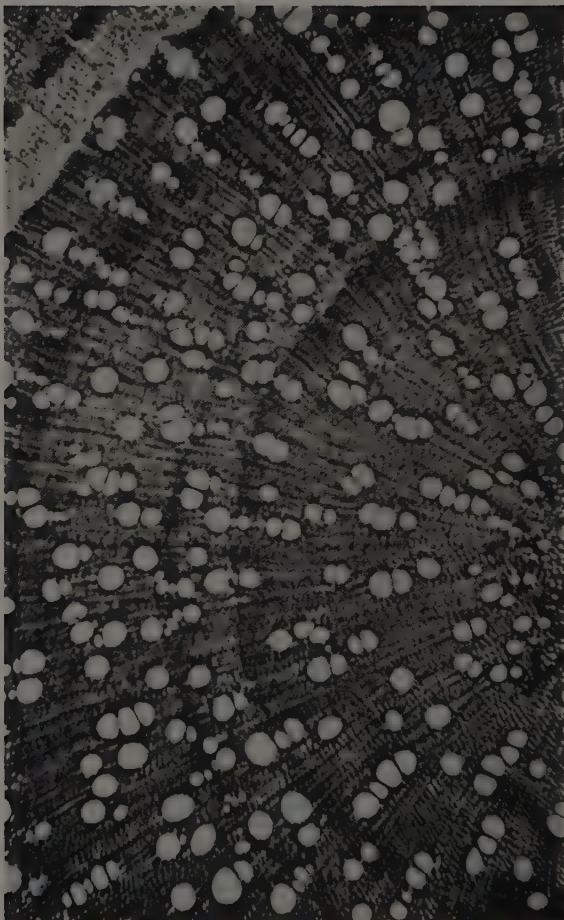

Fig. 12. Cross section of normal sweet-orange root from old tree.

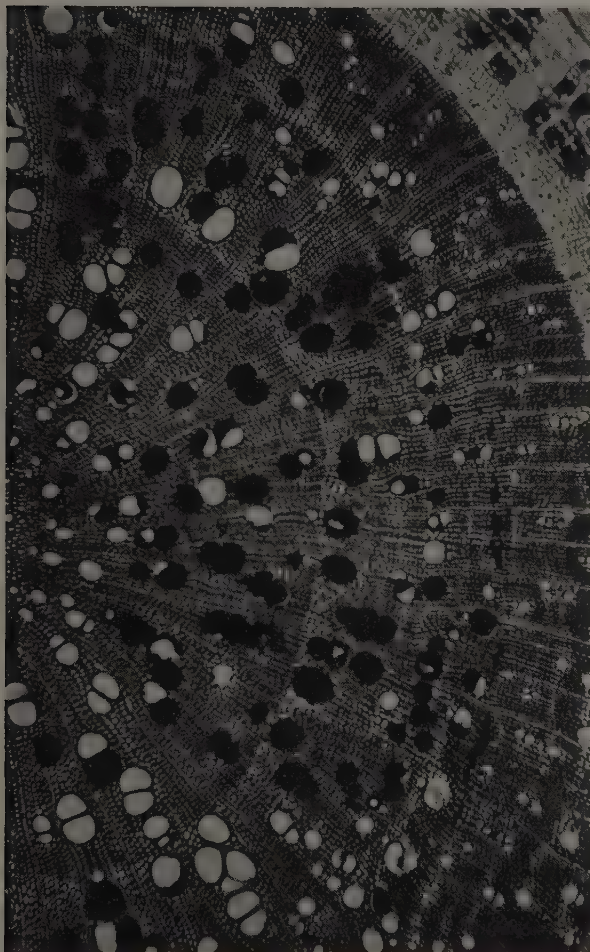

Fig. 13. Cross section of sweet-orange root from old tree, with gum deposit in trachea.

It has not been determined whether root activity is initiated by food stored in the leaf or by immediate availability of photosynthetic products made in the leaf. When a leaf is taken from the tree and placed in the propagating frame translocation must necessarily cease, and food which is not used up in respiration must accumulate until the newly formed roots can utilize it. Attempts were made to deplete the starch content of the leaves before taking them from the tree by covering them with black paper and by keeping potted plants in the dark. However, the starch did not disappear from the leaves, even after the plants had been kept in the dark room for three weeks, at which time the leaves began to drop.

TABLE 5

CORRELATION OF LEAF AREA AND LEAF WEIGHT OF SINGLE-LEAF CUTTINGS AND LEAFY STEM CUTTINGS WITH ROOT PRODUCTION

Variety	Type of cuttings	Number of cuttings	Correlation				
			Fresh weight of leaves with		Total leaf area with		
			Fresh weight of roots	Dry weight of roots	Fresh weight of roots	Dry weight of roots	Total length of roots
Eureka lemon	Single leaf	35	0.86±0.03	0.83±0.04	0.81±0.04	0.76±0.05	0.25±0.11
Eureka lemon	Leafy stem	50	0.94±0.01	0.92±0.02	0.99±0.00	0.84±0.03	0.42±0.08
Valencia orange	Leafy stem	28	0.72±0.06	0.65±0.07	0.78±0.05	0.78±0.05	....

TABLE 6

QUANTITATIVE ROOT PRODUCTION OF CITRUS CUTTINGS

Variety	Number of cuttings	Period of growth	Fresh weight of roots per 100 grams of fresh weight of leaves	
			Mean	Standard deviation
		days	*grams*	*grams*
Eureka lemon*	28	90	70.2±2.7	20.9±1.9
Valencia orange*	22	90	28.0±1.3	8.7±0.9
Eureka lemon	28	64	49.3±0.7	5.7±0.5
Valencia orange	28	64	30.7±1.0	7.9±0.7
Eureka lemon	20	77	51.0±1.1	7.3±0.8
Valencia orange	20	77	40.5±1.7	11.3±1.2
Marsh grapefruit	10	77	27.3 —	....
Eureka lemon*	54	64	38.6±0.9	10.2±0.7
Navel orange*	47	64	23.6±1.0	10.1±0.7

* Single leaf cuttings without stems (fig. 2).

TABLE 7

DEPTH OF PALISADE TISSUE EXPRESSED AS PERCENTAGE OF LEAF THICKNESS*

Variety	Sample No.	Number of leaves	Mean	Standard deviation
Chalcas exotica	1	45	31.9±0.2	2.1±0.2
Citron	1	30	30.0±0.3	2.6±0.2
Eureka lemon	1	29	28.6±0.3	2.4±0.2
	2	32	28.7±0.2	1.7±0.1
	3	30	29.3±0.2	1.6±0.1
	4	30	29.4±0.2	1.9±0.2
	5	45	28.9±0.2	2.3±0.2
	6	28	28.3±0.2	1.6±0.1
	7	25	28.8±0.2	1.7±0.2
	8	30	29.2±0.1	1.2±0.1
	9	45	28.8±0.2	1.8±0.1
	10	30	29.2±0.2	1.3±0.1
	11	30	28.2±0.2	1.8±0.2
	1–11	354	28.8±0.1	2.0±0.1
Lisbon lemon	1	30	29.0±0.3	2.3±0.2
Rough lemon	1	30	28.2±0.2	1.9±0.2
	2	30	28.9±0.2	2.0±0.2
Rusk citrange	1	39	27.6±0.2	2.0±0.2
Dancy tangerine	1	30	25.0±0.3	2.4±0.2
Sour orange	1	26	24.3±0.2	1.8±0.2
	2	30	24.8±0.3	2.1±0.2
Valencia orange	1	33	23.9±0.3	2.4±0.2
	2	30	23.3±0.2	1.3±0.1
	3	37	24.7±0.3	2.3±0.2
	4	45	23.7±0.2	1.8±0.1
	5	30	23.3±0.3	2.5±0.2
	6	25	24.3±0.4	2.7±0.3
	7	30	24.3±0.3	2.4±0.2
	8	30	23.2±0.4	3.0±0.3
	9	30	23.7±0.3	2.8±0.2
	1–9	290	23.8±0.1	3.2±0.1
Washington Navel orange	1	39	23.3±0.3	2.3±0.2
	2	30	22.8±0.2	1.6±0.1
	3	30	22.4±0.3	2.1±0.2
	4	30	22.6±0.2	1.5±0.1
	1–4	129	22.8±0.1	2.0±0.1
Marsh grapefruit	1	30	22.0±0.2	1.5±0.1
	2	30	21.6±0.2	1.7±0.2
	3	30	22.3±0.3	2.2±0.2
	4	33	21.6±0.2	1.6±0.1
	5	33	22.0±0.3	2.3±0.2
	6	30	20.7±0.2	2.0±0.2
	7	30	21.3±0.3	2.2±0.2
	1–7	216	21.6±0.1	2.1±0.1
Sampson tangelo	1	30	21.6±0.3	2.1±0.2
Owari satsuma	1	32	21.2±0.2	1.7±0.1
	2	30	20.9±0.2	1.6±0.1

*From: Halma, F. F. Quantitative differences in palisade tissue in *Citrus* leaves. Bot. Gaz. **87**:319–324.

It has been pointed out that cuttings of different citrus species differ in the rate of rooting. The lemon group roots more rapidly than the sweet oranges and these in turn root sooner than the grapefruit. Table 6 shows that the amount of roots produced per unit of

fresh weight of leaf, during a given period and under the same conditions, is greater for the lemon than for the orange and grapefruit. The difference in the growth rate of the different species becomes more obvious as the cuttings develop in the nursery. For example, starting with cuttings having a similar total leaf area, the lemon, within a year, will be about twice as large as the sweet orange.

It has been shown (Halma[8]) that the depth of the palisade tissue expressed as a percentage of the thickness of the leaf is about 20 per cent greater in the lemon than in the sweet-orange leaf. The grapefruit ranks below the orange and the Satsuma mandarin exhibits the lowest value (table 7). Apparently a close relation exists between the degree of palisade development for each species and its ability to root from cuttings and also its subsequent growth rate, based on unit leaf area until the tree begins to fruit.

There are also fundamental differences between the physical and chemical constitution of the sap of Eureka lemon and that of Valencia and Navel orange (Haas and Halma[3]). The sap of normal, mature lemon leaves is less active osmotically, and contains less ash and calcium, than the sap of orange leaves. Furthermore, it has been found (Halma and Haas[4]) that the sap of lemon leaves, on exposure to direct sunshine, increases its concentration more rapidly than that of orange leaves. This increase in sap concentration is due entirely to photosynthetic products, the ash of the sap remaining the same in an exposed and an unexposed situation. While both these differences between the lemon and orange may have a bearing on the different behavior of cuttings of these species, it will be necessary to study the respiratory, photosynthetic, and translocatory processes as well before the causes for these inherent differences in behavior can be safely assigned.

SUMMARY

A method is described by which citrus trees can be grown from cuttings.

A similar method is given for rooting grafted twigs representing various combinations of scion and rootstock.

A method is described by which the rootstock type of mature trees can be propagated.

The importance of the leaf in citrus propagation by cuttings, differences in the response of citrus varieties to conditions favoring rooting, differences in leaf structure, and physical and chemical constitution of the leaf of different varieties, are discussed.

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